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OPERATIONAL TEST AND EVALUATION

THE A/A 37U-15 TOW TARGET SYSTEM

November 1962

HEADQUARTERS
TACTICAL AIR COMMAND
United States Air Force
Langley Air Force Base, Virginia

FOREWORD

This project was ordered by TAC in an effort to provide the F-104 with a superior, more reliable dart tow system. The test was conducted by the 479th Tactical Fighter Wing, George Air Force Base, California.

Individuals responsible for the actual conduct of the test and preparation of this final report are:

Project Officer	Raymond L. Krasovich Capt 479 TFW
Test Director	Carl E. Taylor Lt Colonel 479 TFW
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ABSTRACT

The F-104 aircraft can safely tow the TDU-10B target with the A/A 37U-15 tow system. No modification to the aircraft is necessary and existing wiring is used to launch and recover the target. Maintenance of the system has posed no new or unusual problems. Superior aerodynamic characteristics of the system allow greater flexibility of dart towing than was previously possible.

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1. GENERAL INFORMATION.

a. Introduction.

(1) The following is the final report of the F-104 Tow Target System A/A 37U-15. The test was ordered by TAC Headquarters, Test Order Number 62-16 dated 6 March 1962. Physical testing commenced 19 March 1962 and was completed 4 May 1962.

(2) One tow system was lost when an undampened lateral oscillation occurred on takeoff causing the system to separate from the aircraft pylon.

(3) ASFC participation in the test included the use of the facilities of AFFTC, Edwards AFB, California, for the first flight and taxi tests and furnishing chase aircraft for seven sorties.

b. Background. The A/A 37U-15 Tow System was developed to provide the F-104 with a tow system having improved aerodynamic characteristics, increased reliability, reduce maintenance and improve turnaround time. This system is an outgrowth of the F-105 system (A/A 37U-9) and components are interchangeable with the exception of the target launcher.

2. DESCRIPTION OF THE TEST ITEM. The F-104 Tow Target System consists of a one way tow reel, a Fiberglas pod housing and a target launcher adapter. The TDU-10/B dart target is used with this system. The reel pod is mounted to the left wing pylon and the target launcher adapter boom is mounted to the left side of the pod by two stub struts. The complete system, with or without a target or during towing, is jettisonable. Airborne jettison is accomplished either by the emergency jettison button or by selecting pylons and depressing the bomb button. Ground jettison, which is necessary for a barrier engagement, is accomplished by the emergency jettison button. Release of the target initiates the reel-out of the 11/64" armored cable. The reel-out rate is controlled by a centrifugally actuated disc type brake. The dart is recovered by the "Wheelus" method which consists of a parachute housed in a small canister attached to the tow cable approximately thirty feet ahead of the target. Severing the tow cable, which is accomplished by an explosive scuib and cable cutter, reverses the position of the parachute canister and the resulting change in aerodynamic forces deploys the parachute. The tow system is fabricated by the Anderson-Greenwood Co. of Houston, Texas. The test vehicle was a standard F-104C of the 479th Tactical Fighter Wing configured with a left wing pylon.

3. PURPOSE OF THE TEST. The purpose of the test is to conduct an engineering evaluation of the F-104 Tow Target System.

4. SCOPE OF THE TEST. The scope of the test was directed toward but not limited to the following:

a. Operational usefulness and the development of operational tactics and techniques.

b. System shortcomings, maintenance and support facilities required and parts consumption.

c. Personnel requirements with respect to special skills and training required, special tools and test equipment.

d. Turnaround time and estimated life of equipment.

5. CONCLUSIONS.

a. The A/A 37U-15 Tow Target System is compatible with the F-104 aircraft.

b. The modification of the system by shortening the boom and installing a target nose guide has effectively eliminated the oscillation problem.

c. With the installation of a diode in the release circuit, existing aircraft wiring can be used with this tow system.

d. Greater reliability in launch, towing and recovery is anticipated with the use of this system.

6. RECOMMENDATIONS.

a. Recommend that the A/A 37U-15 be utilized as a standard tow system for F-104 aircraft.

b. Recommend that existing aircraft circuitry be used in this installation.

c. Recommend that the Anderson-Greenwood Co. study the possibility of lowering the launcher adapter boom to allow the use of land flaps on the F-104.

d. The following airspeed and "G" limitations are recommended using 11/64" armored tow cable.

Maximum airspeed with system and target -	325 KIAS	1.5 "G"
Target launch airspeed	210 KIAS	1 "G"
Maximum tow airspeed	400 KIAS or 1.1 Mach	2 "G"
Target drop airspeed	210 KIAS	1 "G"
Flight with system only	450 KIAS or 1.3 Mach	3 "G"

7. TEST RESULTS AND DISCUSSIONS.

a. Test Environment and Procedures. The test was conducted at George AFB, Calif, with certain phases being conducted at Edwards AFB, Calif. Physical testing commenced 19 March 1962 with the mating and electrical check-out of the tow system to the F-104. Then the aircraft was flown to Edwards

AFB while the system and targets were trucked to the test site. Taxi tests and the first flight with the tow system were conducted at Edwards AFB. The test site was moved to George AFB and on the fifth test sortie, the tow system and target developed a severe oscillation on takeoff and separated from the pylon. Testing was halted at this point and a complete re-evaluation of the system/target oscillation was accomplished resulting in a modification of the system. Testing was resumed 25 April 1962 at Edwards AFB with a modified system. The modification proved successful and testing was resumed at George AFB using the tow system on scheduled dart firing sorties. Dart recoveries were made at Edwards AFB on the initial flights and the remainder were made at Cuddeback air-to-ground range. The "Wheelus" method of recovery was used successfully until a shortage of modified canisters forced its abandonment. Various tow airspeeds and altitudes were tested. Normal launch and recovery procedures and techniques were used and found satisfactory. Aircraft was configured with and without tip tanks with satisfactory performance.

b. Test Results and Analysis.

(1) The tow system was mated to the aircraft with no problem and the TDU-10B target was easily hung to the adapter boom. It was determined that rather than add another wire and control box to the aircraft, it would be more advantageous to use existing aircraft wiring and time the tow cable reel-out. The Wing could not afford to wire all F-104 aircraft to the configuration depicted in the original drawings, nor would it have been feasible to modify a small number of aircraft for this purpose since it is necessary to have all F-104 aircraft capable of performing a tow mission.

(2) The rocket firing circuit was used for launch and recovery of the dart. The launch is affected by selecting either L.H. or Both on the rocket selector and depressing the bomb button. The transfer switch in the MA-4A rack will then transfer power to the cable cutter assembly upon the next depression of the bomb button and actuate the cable cutter.

(3) During the electrical checkout, it was discovered that after releasing the bomb button an inductive voltage kick was being placed across the cutter cartridge and was of sufficient magnitude to ignite the cutter cartridge. Investigation revealed that the inductive kick was caused by the transfer switch completing its circuit before the magnetic field built up at the release solenoid had collapsed, thus allowing the current created by the collapsing field to flow through the transfer switch and then on through the cutter cartridge igniter. This problem is common to the MA-4A rack. Four racks were checked with the same results.

(4) The standard fix for this occurrence, as encountered in many control and computer circuits, is to place a diode across the coil windings. This diode represents a high resistance to the coil energizing current, and a very low resistance to the current caused by the collapsing magnetic field. This allows the magnetic field to collapse practically upon removal of the energizing current.

(5) A diode, type IN 315, was placed across the MA-4A rack release solenoid windings. This fix was ground checked satisfactorily and further proven on the test flights. On one test flight the diode connection was broken during loading which resulted in the cable cutter actuating at dart launch. The system was repaired and functioned properly on subsequent missions. The diode will be built in the wiring on subsequent tow systems.

(6) High speed taxi checks were carried out at Edwards AFB, Calif. For these tests the aircraft was configured without tip tanks and with the system and target. Taxi speeds of 160 KIAS with the flaps up were achieved and drag chute deployment checked with no problems.

(7) The first flight was made with the system only and without tip tanks. Takeoff and landing characteristics were satisfactory. Aircraft then climbed to 35,000 feet. Normal climb speeds were used and acceleration to 1.42 mach was initiated. As the airspeed increased the lateral trim requirement increased to the point where at 1.2 mach full right aileron trim was required. As mach number increased more right aileron was needed until approximately $2\frac{1}{2}$" stick displacement was required at 1.42 mach. Mach number was not increased due to the rapidly increasing lateral control requirements.

(8) Four positive "G's" were applied at 25,000 feet and .95 mach with no adverse affects.

(9) The first three flights with the system and target were made with the aircraft configured without tips. The first flight was made from Edwards AFB and normal dart takeoff technique was used, i.e., leaving nose wheel on the ground until 190 KIAS was reached and then lifting nose wheel and flying the aircraft off. This technique is successful and usually results in a slight dragging of the lower dart fin, however, this does not affect the flying characteristics of the target. Climb out to launch altitude was accomplished at 300 KIAS.

(10) During cruise to launch area at 300 KIAS and 8000 feet an undampened lateral oscillation of the target occurred when aircraft was flown through turbulent air. The target oscillated laterally about 18" either side of center line with a frequency of about $\frac{1}{2}$ second. This oscillation was quite noticeable in the tow aircraft and dampened out only after the airspeed had been reduced to 260 KIAS. During this oscillation the 30 foot nylon leader rope, which had been taped to the leading edge of the dart wing, broke loose and was trailing behind the dart, aggravating the oscillations.

(11) The aircraft was slowed to launch speed of 205 KIAS at 10,000 feet and the target was launched successfully. Reel-out time for 2200' of 11/64" armored cable was 2 minutes and 32 seconds. The reel-out was very smooth and a hardly noticeable tug was felt as the cable reached full extension. Normal towing procedures were used with no problems.

(12) Recovery at 205 KIAS and the target altitude of 200 feet was made at Edwards AFB and was completely successful. The only damage to the dart was the nose extrusion holding the nose weights was bent. This unit was replaced and the target flew two more successful missions.

(13) On the next mission the nylon leader again broke loose from the dart and trailed behind the target. On launch the leader wrapped around a dart wing, causing the target to be lost.

(14) The problem of the nylon leader breaking loose from the dart was solved by using safety wire to affix the leader in place instead of tape. This fix was successful on all subsequent flights.

(15) Launch and reel-out were successful on the third mission with a reel-out time of 2 minutes and 30 seconds. Target was towed to a speed of 1.1 mach in level flight at 38,000 feet. Acceleration was very slow and higher mach number could be reached if time and fuel permitted.

(16) The recovery system again functioned properly and the only damage to the target was the bent nose extrusions.

(17) On the next mission the aircraft was configured with tip tanks. Normal takeoff techniques were employed and immediately after lift-off a severe vibration and oscillations occurred and shortly thereafter the system separated from the aircraft.

(18) The mounting lugs were retained by the pylon shackles and the threads showed evidence of stripping. The chase aircraft was just moving into position when the system separated. Airspeed at the time of the incident was approximately 260 KIAS. The wreckage of the system and target was recovered and no evidence of structural failure could be discovered. It was determined that the separation was caused by an undampened oscillation.

(19) At this point, operations were suspended and a complete evaluation of the oscillation characteristics of the system accomplished. A complete report by Mr. Walter L. Moss, Contractor Representative, is contained in Appendix "A".

(20) As a result of this study the boom length was reduced 12" and a target nose guide added. The reduction in boom length increased the rigidity of the system by 15.3% and the nose guide prevents independent lateral oscillation of the target.

(21) Two modified systems were sent to George AFB and testing resumed 25 April 1962.

(22) Structural integrity of the system was checked in flight at 1.1 mach at 35,000 feet and 4 positive "G's". Aircraft was configured with tip tanks and first flight with the target was accomplished from Edwards AFB. Entire flight was flown with the target attached and attempts were made to induce oscillations. Configurations were varied to include

flaps, landing gear and speed brake cycling and full rudder kicks. The aircraft was then flown to maximum speed of 350 KIAS at 13,000 feet and flown in moderate to severe turbulence at 300 KIAS. At no time or configuration did the target show any tendency to oscillate or flutter.

(23) On landing, 210 KIAS was used on final approach and touchdown was made at approximately 180 KIAS. The higher airspeed was used to preclude dragging the dart. The drag chute was deployed at 160 KIAS. For an unknown reason nose wheel steering was not engaged and the aircraft picked up a drift to the right that could not be stopped until left brake was used. With nose wheel steering engaged, no directional control problems should be present.

(24) Examination of the target and system revealed no damage other than a slight scraping on the bottom of one dart wing.

(25) The next flight was made with the same configuration with a target launch and recovery. Maximum tow airspeed reached was 1.1 mach at 35,000 feet and maximum altitude of 42,000 feet was reached. The dart was towed at 400 KIAS at 11,000 feet with no adverse effects. The recovery was successful.

(26) The next six sorties flown were normal dart firing sorties and both tow systems were used for this phase of the test. The systems functioned properly on five missions. On one mission, already mentioned, the diode connector was broken and the cable cutter actuated on launch.

(27) The normal dart tow pattern and routes were used for the tow sorties. 1500 feet of 11/64" armored was used and an average reel-out time of 1 minute and 30 seconds was recorded. Launch conditions were 210 KIAS and 10,000 feet. Recoveries, made with and without the parachute, were successful and accomplished at Cuddeback air to ground range.

(28) The dart pattern flown started .75 mach at 30,000 feet. A left descending turn (approximately 220°) maintaining .75 mach and 1.75 "G" is made to 27,500 feet while the fighters are making a firing pass. Aircraft is then leveled and firing aircraft positioned and right descending turn is made to 25,000 feet. Upon completion of this turn a climb is initiated back to 30,000 feet and the pattern is repeated.

(29) Recovery conditions are: Target 200 feet above ground (3800 feet indicated altitude at Cuddeback Range) 210/220 KIAS.

(30) With the completion of the firing sorties the systems were disassembled and the stressed parts magnifluxed. Stub strut, suspension lugs, and attaching bolts showed no evidence of stress or cracking. Three of the four dart sway braces, however, developed cracks on the inside radius of the 90 degree bend. Both sway braces on the system which had flown 11 sorties were cracked while only one sway brace on the system which had flown 4 sorties was cracked. With continued use a failure could have resulted which would allow the target to roll around its

longitudinal axis on the launcher. This could lead to many problems and there is a possibility that a similar occurrence caused the loss of the first system. There is no positive evidence to support this theory, however. All of the sway braces have been returned to the contractor for evaluation.

c. Tactics and Techniques:

(1) The aerodynamic qualities of the tow system will allow a greater latitude in tow operations than was previously available. Due to the local range limitations a figure eight tow pattern is mandatory. However, higher tow airspeeds and "G" loadings can now be realized thus giving pilots more realistic training. During the course of the test, tow patterns were flown at varying airspeeds up to .95 mach and 2 "G" turns, and were found compatible and satisfactory with local range limitations and the aircraft. Towing at these speeds would allow the firing aircraft to fire at 1.1 to 1.2 mach speed range where aircraft handling is much superior to subsonic flying.

(2) Due to the clean design of the tow system, fuel consumption is kept at an acceptable level for this tow mission. Using the present airspeed for the tow mission fuel consumption is greatly reduced compared to the homemade tow system presently in operation. Lateral trim required is slightly more at lower airspeed and as speed increases, the lateral trim increases rapidly. Flying with tip tanks the lateral trim change increases sharply at .9 mach. This rapid trim change can be trimmed out and is not present without tip tanks. The overall asymmetric handling characteristics of the F-104 with the system and target are satisfactory throughout the speed range tested.

(3) Normal takeoff techniques for the system includes setting rudder trim at the three o'clock position, using nose wheel steering to approximately 130 KIAS, nose wheel is left on the ground until 190 KIAS and then lifted off and aircraft is flown off. There is a tendency for the left wing to drop but this is easily correctable with aileron and can be trimmed out.

(4) Launch technique is to slow aircraft to 210 KIAS at approximately 10,000 feet; select rocket function and depress bomb button. Airspeed is maintained for 1 minute and 45 seconds or until reel-out is felt by pilot. Reel-out time for 1500 feet of 11/64" armored cable is 1 minute and 30 seconds. Aircraft is then accelerated to 350 KIAS and a full afterburner climb to firing altitude is made.

(5) Recovery is accomplished at 220 KIAS with target approximately 200 feet above the ground, rocket function selected and bomb button depressed at target drop point. If the parachute recovery system is used, the accuracy of the target drops is very good.

(6) Since the flaps are restricted to takeoff and up position only with the tow system installed, takeoff flap landing procedures apply.

The final approach airspeed should be flown at 200 KIAS and touchdown made at 165-170 KIAS under normal conditions. Lateral and directional control becomes a problem in 90 degree crosswinds above 15 knots.

(7) No specialized or unusual techniques are needed for a qualified tow pilot to fly this system.

d. Maintenance.

(1) Maintaining the system does not appear to pose any additional problems. The reel and centrifugal brake should require very little if any continuing maintenance. These parts showed little or no wear at the end of the test.

(2) Mounting the system is accomplished using the MJ-1 and offers no unusual problems.

(3) Installing the spool and cable in the system posed some problems early in the test period. This item weighs approximately 175 pounds and is very awkward to "manhandle" into position. The ground clearance was not sufficient to allow an MJ-1 to be used. An adapter was designed by Capt Jensen of Det 4, ASD, Eglin AFB, Fla and proved most effective in loading the spool. This adapter which will accept a spool with cable is mounted on a hydraulic jack which is mounted on a three-castered stand. The adapter, loaded with spool and cable, is wheeled under the system and the spool is jacked up into position and the retaining shaft inserted. The cable is then threaded through the guide and is ready for attachment to the dart cable. The cable is then looped through the dart cable (or parachute canister if used) and swedged. The swedging posed a problem in that no 11/64" swedging tool was available on the station. One was finally obtained from Eglin AFB, Fla and eased this problem considerably.

(4) Initially turnaround times for the system were approximately 1½ hours which was unacceptable. The biggest problem was replacing the spool of cable, however, the loading adapter eased this problem. As personnel became familiar with the system, the turnaround time was cut to approximately 30 minutes. This time is quite acceptable but is not an improvement over the turnaround time now experienced with the homemade tow system. The same number of A&E personnel (three) are required to turn-around either system.

(5) An extremely long life is anticipated for this tow system. The results of this test indicate that parts consumption should be very low for this system. The explosive squib cable cutter is the only part needing replacement after each sortie.

(6) An 11/64" swedging tool is the only special tool needed for the operation of this system.

(7) The dart nose guide pin (See Figure 1) was locally manufactured and can be recovered and reused on the targets.

(8) Listed below is a list of peculiar tools and consumable items:

	Item	Stock Number
(1)	TDU-10/B Target	FSN 6920-613-0312
(2)	11/64 inch Armored Cable	FSN 4010-202-2087 or FSN 4010-297-1109
(3)	7/16 inch diameter nylon rope	FSN 4020-486-8767
(4)	Nico-press swaging sleeve, 3/16 inch	FSN 4030-132-9159
	substitute item	FSN 4030-132-9162
(5)	Nico-press swager pliers	FSN 5120-303-1046
(6)	MK-23 Mod 0 Cartridge	FSN 1375-632-8714-X036

e. Deficiencies.

(1) The cracking of the dart sway braces is considered a minor deficiency of the tow system.

(2) The contractor has directed better quality control on the bending of the sway braces. This action is expected to solve this discrepancy.

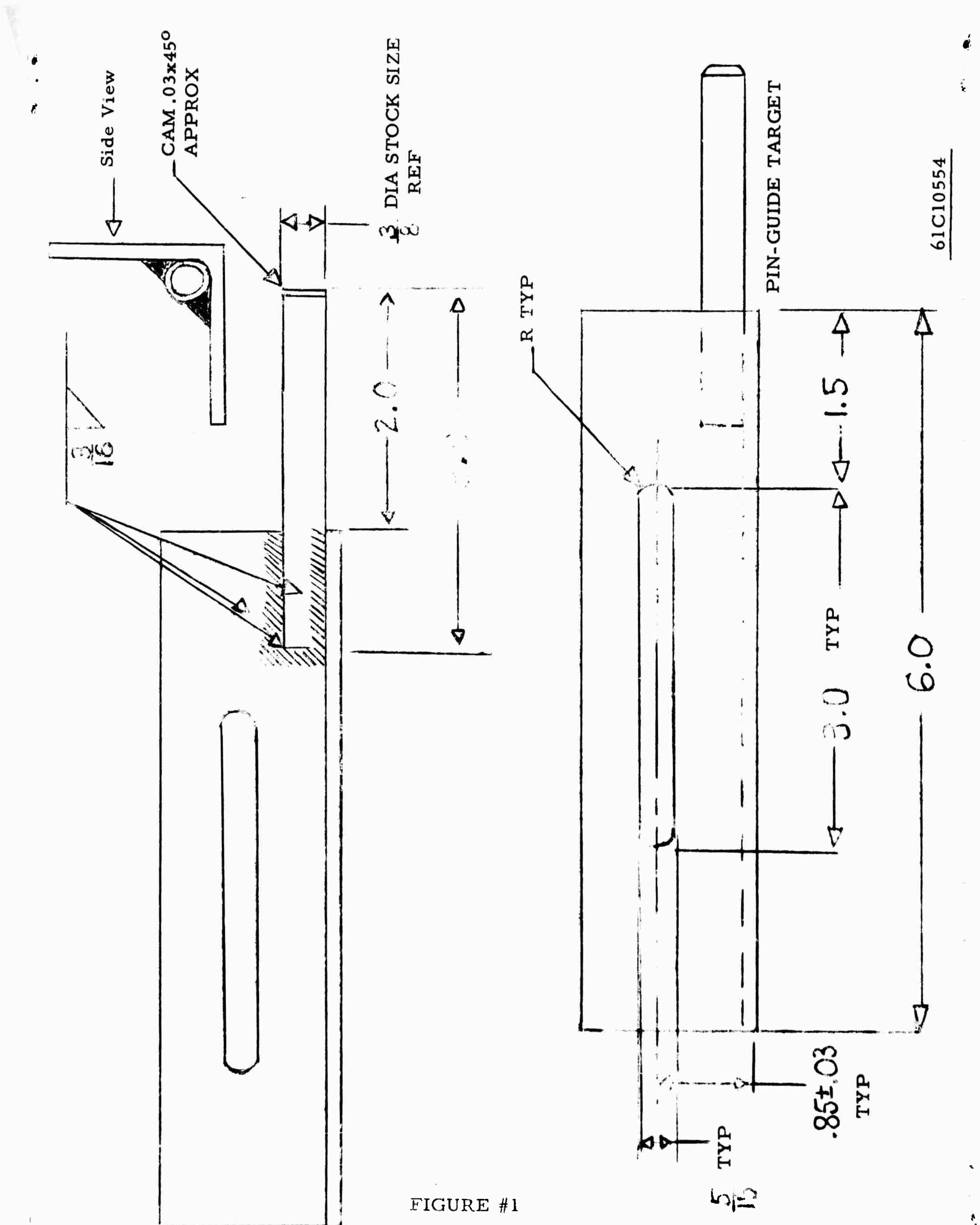
(3) The transfer switch in the MA-4A rack is not satisfactory in its operation in that a diode must be placed across the coil windings to prevent an inductive kick from firing the cable cutter on target launch.

8. SUMMARY.

a. The A/A 37U-15 tow system is compatible with the F-104 aircraft. Existing aircraft wiring is used to launch and recover the target.

b. The aerodynamic qualities of the system offer more realistic tow patterns and training than are now available. The increased reliability of the tow system will increase training and mission effectiveness.

c. Maintenance of the system presents no unusual problems and turnaround times are acceptable.



Side View
CAM .03x45° APPROX
3/8 DIA STOCK SIZE REF
3/16
2.0
R TYP
PIN-GUIDE TARGET
61C10554
1.5
3.0 TYP
6.0
.85±.03 TYP
5/16 TYP

FIGURE #1

DISTRIBUTION LIST

HQ USAF	
AFORQ-TA	2
AFOOP-TA	2
AFMME	2
SMAMA	2
USAFE	2
PACAF	2
ASD	
ASZF	3
Det 4, ASD	
ASQT	5
APGC	
TACLO	2
PGWQ	2
AFLC	
MCFLC	2
OOAMA	5
ASTIA	
TIS	1
9AF	2
12AF	
OOD-S	2
DM	2
831st AD	2
479 TFW	5
4520 CCr Tng Wg	
TFW-R&D	2
TFW-TTS	2
7272 AB Wg	
DOWT	2
AGOS	
N-8	1
HQ TAC	
DOOP-OF	1
DOTR-FF	2
DMSA	2
DMEM	2
OIH	1
SEG	1
DORQ-T	10

APPENDIX A

ANDERSON-GREENWOOD REPORT 592

DART TOW SYSTEM - F-104

AGCO REPORT 592

DART TOW SYSTEM - F-104

IMPROVEMENT ON TARGET SUSPENSION SYSTEM
TO REDUCE TARGET OSCILLATIONS OCCURRING DURING FLIGHT

By: /s/ Walter L. Moss, Jr.
Walter L. Moss, Jr.
Project Engineer

Approved: /s/ A. L. Presnal
A. L. Presnal
Chief Engineer

Date: 19 April 1962

INTRODUCTION:

Flight tests made at George Air Force Base have indicated possible harmonic oscillations of the target at a speed slightly higher than 300 knots. These flight tests indicated that a disturbance to the static condition of the target being flown at 300 knots would cause a lateral oscillation to occur. Maintaining 300 knots, this oscillation would neither dampen itself out, nor amplify itself; thus indicating that the speed of 300 knots was giving a disturbing force which was close to, but not quite, the natural frequency of the oscillating system. A decrease in speed would cause these the lateral oscillations to stop, thus indicating that the critical speed which would produce a harmonic disturbing force was some speed above 300 knots.

DISCUSSION:

There are two oscillating systems which can be considered. One in which the target is assumed to pivot laterally at its support and the aerodynamic forces acting on the target are considered along with the natural frequency of the target suspension system, namely the launcher boom. This could occur as shown in Figure 1. The buildup in intensity of this oscillating system is clearly shown in Figure 1 - 4, and is caused by aerodynamic forces tending to deflect the boom in the direction in which it is already deflected. The oscillating system can be eliminated by causing the aerodynamic forces always to oppose boom deflection. This has been accomplished by laterally fixing the nose of the target in relation to the boom, so that for lateral displacements the target will rotate about its nose, rather than about its support point. The exact analysis of this oscillating system is very difficult, and has not been attempted, rather, a graphical approach has been used.

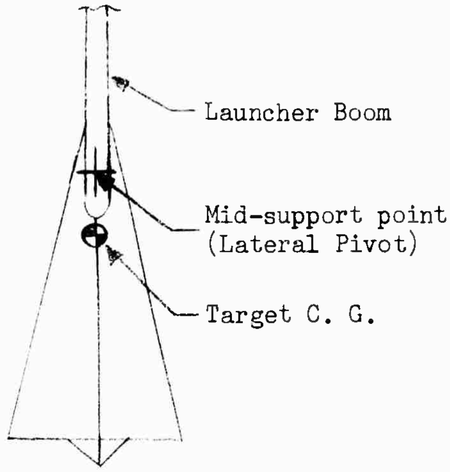
The second oscillating system is similar to a flutter problem, treating the target as a fixed concentrated load at the end of the boom and assuming the disturbing force as the aerodynamic forces acting on the system. The intensity of oscillations depends on the ratio of the frequency of the disturbing force (in our case considered a constant at a constant speed) to the natural frequency of the vibrating system. When the two frequencies are equal the intensities build up infinitely, assuming no damping, and drop rapidly off as the frequencies differ from each other. To lower the intensity of oscillations, the disturbing force being considered a constant, the natural frequency of the oscillating system must be changed. Two methods of accomplishing this are:

1. To shorten the length of the boom.

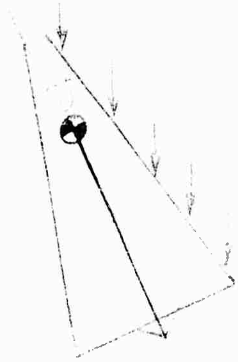
2. Increase the section modulus of the boom, by increasing the diameter and/or increasing the wall thickness.

The easiest method to accomplish physically was to shorten the length of the boom and fit tests on the aircraft showed that 12" could be removed from the boom length. As shown in the calculations following, this represents a 15.3% change in the natural frequency of the system, and it is believed that this change will be more than sufficient to stop this type of oscillations.

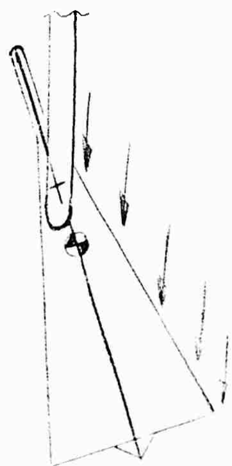
If flight tests prove that further changes are required, layouts have shown that the boom diameter can be increased to 5 inches. This necessitates changes in casting patterns and boom design, but is physically possible. This increase to a 5" O.D. X .250 wall will further increase the frequency by 48.7% or a total of 56.5% increase in frequency for increasing boom diameter and shortening its length.



1. Target and boom in static condition

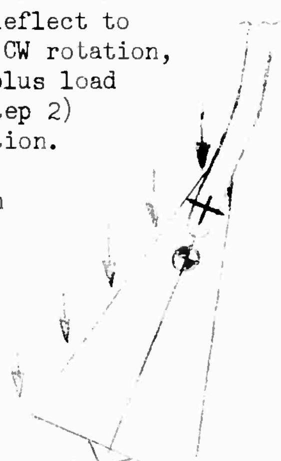


2. Displaced target with aerodynamic forces tending to oppose boom deflection.



3. Boom is now straight but target is still rotated. Aerodynamic forces tend to cause boom to deflect to left and give target a CW rotation, but inertia of target plus load applied by boom (see step 2) have prevented CW rotation.

4. Boom has deflected to left. Force of boom Fwd of target C. G. is now causing CW rotation of target. This rotation has not yet taken place due to inertia of the target and aerodynamic forces are causing further boom deflection.

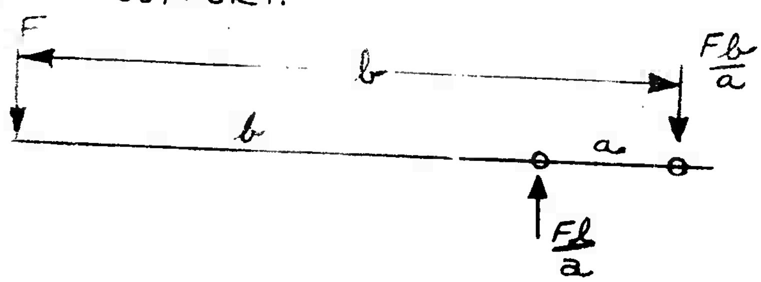


5. Target inertia has been overcome and target has rotated to the point where the aerodynamic forces act in opposite direction. This is the same condition reversed as shown in Step 2, cycle continues building up in intensity.

FIGURE 1

TO DETERMINE THE PERIOD OF OSCILLATION OF THE BOOM AND TARGET IN THE HORIZONTAL PLANE

THE DEFLECTION Y RESULTING FROM THE FORCE F IS DETERMINED, ASSUMING PIVOTED SUPPORTS AT BOOM SUPPORT.



FROM "FORMULAS FOR STRESS AND STRAIN" ROARK 3RD EDITION p 94

$$y = \int \frac{Mm}{EI}\,dx$$

M: BENDING MOMENT IN TERMS OF x

m: BENDING MOMENT IN TERMS OF x CAUSED BY A 1# FORCE ACTING AT POINT y IS TO BE FOUND.

EI = CONSTANT

$$\therefore EI\,y = \int Mm\,dx$$

STARTING AT LEFT END

$x = 0$ TO $x = b$

$$M = -Fx \qquad m = -x$$

$x = b$ TO $x = l$

$$M = -Fx + \frac{Fl}{a}(x-b) \qquad m = -x + \frac{l}{a}(x-b)$$

$$= F\left[-x + \frac{l}{a}(x-b)\right]$$

$$= Fx\left(\frac{l}{a}-1\right) - \frac{Flb}{a} \qquad = x\left(\frac{l}{a}-1\right) - \frac{lb}{a}$$

$$EI\,y = \int_{x=0}^{x=b} (-Fx)(-x)\,dx + \int_{x=b}^{x=l} \left[Fx\left(\frac{l}{a}-1\right) - \frac{Flb}{a}\right]\left[x\left(\frac{l}{a}-1\right) - \frac{lb}{a}\right] dx$$

$$\begin{array}{r} Fx\left(\frac{l}{a}-1\right) - \frac{Flb}{a} \\ x\left(\frac{l}{a}-1\right) - \frac{lb}{a} \\ \hline \end{array}$$

$$-\frac{Fx\,lb}{a}\left(\frac{l}{a}-1\right) + \frac{Fl^2b^2}{a^2} + Fx^2\left(\frac{l}{a}-1\right)^2 - \frac{Flbx}{a}\left(\frac{l}{a}-1\right)$$

$$= -\frac{Fx\,lb}{a}\left(\frac{l-a}{a}\right) + \frac{Fl^2b^2}{a^2} + Fx^2\left(\frac{l-a}{a}\right)^2 - \frac{Flbx}{a}\left(\frac{l-a}{a}\right)$$

BUT $l-a=b$, SO

$$-\frac{Fx\,lb^2}{a^2} + \frac{Fl^2b^2}{a^2} + \frac{Fx^2b^2}{a^2} - \frac{Flb^2x}{a^2}$$

SO

$$EI_{\delta} = F\int_{x=0}^{x=b} x^2\,dx + \frac{F}{a^2}\int_{x=b}^{x=l}\left(-lb^2x + l^2b^2 + b^2x^2 - lb^2x\right)dx$$

$$= F\left[\frac{x^3}{3}\right]_0^b + \frac{F}{a^2}\left[-\frac{lb^2x^2}{2} + l^2b^2x + \frac{b^2x^3}{3} - \frac{lb^2x^2}{2}\right]_{x=b}^{x=l}$$

$$= \frac{Fb^3}{3} + \frac{Fb^2}{a^2}\left[-\frac{lx^2}{2} + l^2x + \frac{x^3}{3} - \frac{lx^2}{2}\right]_{x=b}^{x=l}$$

$$= \frac{Fb^3}{3} + \frac{Fb^2}{a^2}\left[-lx^2 + l^2x + \frac{x^3}{3}\right]_{x=b}^{x=l}$$

$$= \frac{Fb^3}{3} + \frac{Fb^2}{3a^2}\left[-3l(l^2-b^2) + 3l^2(l-b) + l^3 - b^3\right]$$

$$= \frac{Fb^3}{3} + \frac{Fb^2}{3a^2}\left[-3l^3 + 3lb^2 + 3l^3 - 3l^2b + l^3 - b^3\right]$$

$$EIy = \frac{Fb^3}{3} + \frac{Fb^2}{3a^2}\left[l^3 - 3l^2b + 3lb^2 - b^3\right]$$

$$= \frac{Fb^3}{3} + \frac{Fb^2}{3a^2}(l-b)^3 \qquad l-b = a$$

$$= \frac{Fb^3}{3} + \frac{Fb^2 \cancel{a^3}}{3\cancel{a^2}} = \frac{Fb^3 + Fb^2(l-b)}{3}$$

$$= \frac{F}{3}(b^3 + lb^2 - b^3) = \frac{Flb^2}{3}$$

$$F = \frac{3EIy}{lb^2}$$

IF F IS REMOVED AT DISPLACEMENT y

$$\ddot{y} = \frac{F}{M} \qquad M = \text{MASS OF MOVING BODY}$$

$$\ddot{y} = -\frac{3EIy}{lb^2M}$$

NEGATIVE SIGN BECAUSE $\ddot{y}$ IS IN OPPOSITE DIRECTION OF y.

HARMONIC MOTION (DAMPING NEGLECTED)

$$\ddot{y} = -\frac{ky}{M} \qquad k = \frac{3EI}{b^2l}$$

PERIOD OF OSCILLATION = $P = 2\pi\sqrt{\frac{M}{k}}$

CONSIDERING $\overline{M}$ AS A CONSTANT EI AS CONSTANT

$$\frac{P_2}{P_1} = \sqrt{\frac{k_1}{k_2}} = \sqrt{\frac{b_2^2 \ell_2}{b_1^2 \ell_1^2}}$$

ORIGINAL BOOM CONFIGURATION $b_1 = 8.77$ $\ell_1 = 11.88$

SHORTENING BOOM 1 FOOT $b_2 = 7.77$ $\ell_2 = 10.88$

$$P_2 = P_1 \sqrt{\frac{(7.77)^2 (10.88)}{(8.77)^2 (11.88)}} = .847\, P_1$$

SO THERE WILL BE AN INCREASE OF APPROX 15% IN THE NATURAL FREQUENCY BY SHORTENING THE BOOM CANTILEVER BY ONE FOOT.

CHANGING FROM 3⅛" OD x .313" WALL TO 5" OD x .25 WALL

$$I = .0491 (d_o^4 - d_i^4)$$

CONSIDERING b, ℓ, E AS CONSTANTS

$$P_2 = P_1 \sqrt{\frac{I_1}{I_2}} = P_1 \sqrt{\frac{(3.125)^4 - (2.5)^4}{5^4 - (4.5)^4}} = .513\, P_1$$

CHANGING BOOM SIZE TO 5" OD X .25 WALL WILL INCREASE FREQUENCY 48.7%

IF BOOM IS SHORTENED AND CHANGED TO 5" x .25 WALL

$$P_2 = (.513)(.847)\, P_1 = .435\, P_1$$

FREQUENCY IS INCREASED 56.5%

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Operational Test and Evaluation
The A/A 37U-15 Tow Target System

Publication Review

This report has been reviewed and is approved

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